J. Advanced Cast Austenitic Stainless Steels for High-Temperature Components

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Objectives

- Scale up and produce commercial heats of new CN-12-Plus and CF8C-Plus cast austenitic stainless steels.
- Establish a more complete database for tensile and creep properties.
- Determine resistance to aging, fatigue, and thermal fatigue relevant to exhaust component applications.

Approach

- Produce 500-lb air-melted heats of new stainless steels at several foundries.
- Obtain a more complete tensile and fatigue properties database at Caterpillar.
- Determine relative resistance to thermal fatigue at Caterpillar and resistance to creep at Oak Ridge National Laboratory (ORNL).
- Determine the best alloy for further scale-up and component applications.

Accomplishments

- Produced commercial heats of CF8C-Plus and CN-12-Plus cast stainless steels at two commercial foundries.
- Showed that CF8C-Plus had superior strength compared with CN-12 while retaining the high ductility of standard CF8C. Established superior aging, fatigue, and thermal resistance characteristics of CF8C-Plus up to 850ºC.
- Selected CF8C-Plus for further commercial scale-up and broader casting and component investigation.
- Won a 2003 R&D 100 Award for CF8C-Plus cast stainless steel.

Future Direction

- Complete evaluation of thermal fatigue properties and aging resistance after 10,000 h.
- Characterize microstructural changes after selected high-temperature testing or aging.
- Evaluate the effects of different commercial-scale casting processes on properties of CF8C-Plus steel.

Introduction

Advanced large diesel engines must have higher fuel efficiency as well as reduced exhaust emissions without sacrificing durability and reliability. They require exhaust manifolds and turbocharger housings made from materials that can withstand temperatures ranging from 70 to 750°C or higher in a normal duty cycle. Such materials must withstand both prolonged, steady high-temperature exposure and more rapid and severe thermal cycling. New technologies to reduce emissions and heavier duty cycles will push temperatures in these critical components even higher.

Current diesel exhaust components are made from SiMo ductile cast iron, and higher engine temperatures push such materials well beyond their current strength and corrosion limits. The previous cooperative research and development agreement (CRADA) produced systematic data comparing cast CN12 stainless steel and SiMo cast iron for such diesel exhaust component applications. Those data demonstrated a clear tensile strength advantage of standard CN12 steel above 550–600ºC and even larger advantages in creep strength and fatigue life above 700ºC. The previous CRADA project also developed new modified CN12 and modified CF8C steels with better creep strength and significantly better aging resistance and thermal fatigue resistance than standard CN12. The purpose of this new CRADA project is commercial scale-up of these new modified stainless steel heats, and development of the systematic and thorough database required by designers to optimize component design and qualify them for trial component production.

Approach

Prior work on lab-scale heats (15-lb induction melts with argon cover gas) of modified CN12 and modified CF8C and screening tests (aging, tensile, creep) at 800–850ºC at ORNL provided a composition of each alloy for commercial scale-up. High-temperature fatigue testing at Caterpillar Technical Center has identified a significant advantage of the modified CN12 steel. Two commercial stainless steel foundries have produced 500-lb heats of the modified CN12 and modified CF8C steels for testing and evaluation. One of those commercial foundries has been chosen to produce an additional static cast and a new centrifugally cast heat of the new modified CF8C steel. ORNL is also producing another set of laboratory heats to establish the effect of other minor additions on the high-temperature strength of the new modified CF8C steel.

Technical Progress

Tensile and fatigue testing were completed previously, and thermal fatigue testing was completed during the third quarter of 2003 at Caterpillar. Tensile data on the new commercial scale-up heats of the standard and modified cast stainless steels show CF8C-Plus is about as strong as the standard and modified CN12 steels but still has the same high ductility as standard CF8C steel (Figure 1). An “engineered microstructure” alloy design approach gives the new CF8C-Plus steel a very stable austenite parent matrix phase that is free of the Δ-ferrite typically found in standard CF8C steel in the as-cast condition (Figure 2). The creep strength of CF8C-Plus at high

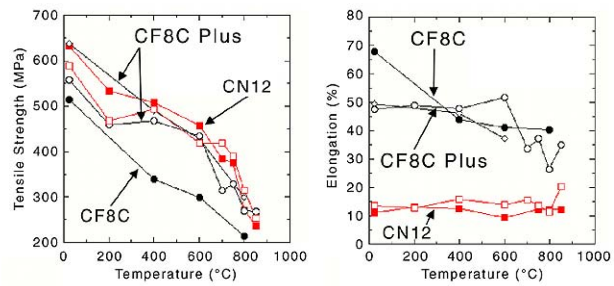

Figure 1. Tensile properties measured by Caterpillar for the commercial scale-up heats of the new modified CN12 and CF8C stainless steels at room temperature to 850°C in air.

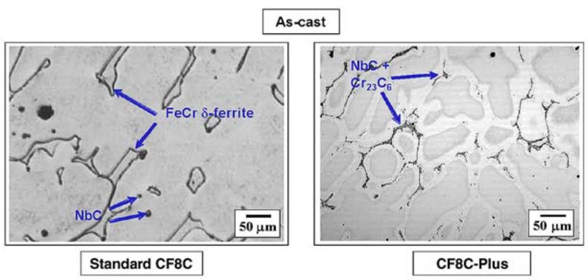

Figure 2. Optical metallography of as-cast microstructures of standard CF8C and the new CF8C-Plus steels.

temperatures comes from nano-scale dispersions of NbC precipitates that form and remain stable and are much finer than those found in standard CF8C steel. Because CF8C-Plus has no Δ-ferrite, it is also free of Δ-phase relative to standard CF8C.

Creep tests of standard CN12 and the modified CF8C (CF8C-Plus) at 850ºC and 35 MPa were completed in 2003. The modified CF8C ruptured after 24,100 h with about 7.8% creep strain, and the test of the standard CN12 was stopped at 15,500 h without failure and less than 1% creep strain. The CF8C-Plus clearly had much better creep resistance than standard, commercial CF8C at 850ºC, and was comparable to CN12 (Figure 3).

CF8C-Plus was deliberately designed to have a combination of good strength and ductility at both higher and lower temperatures in order to achieve its best

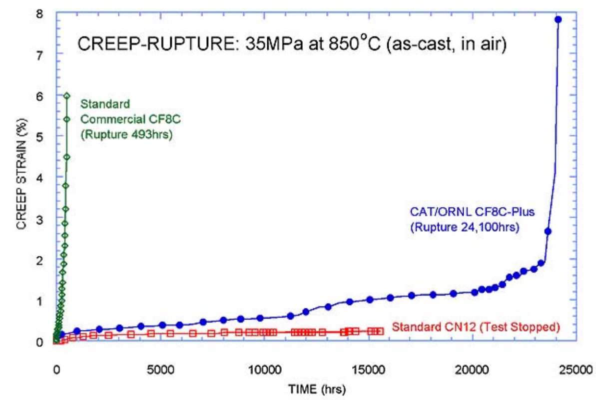

Figure 3. Creep-rupture testing (at ORNL) of standard, commercial CF8C and and CN-12 cast stainless steels and a lab-scale heat of the new CF8C-Plus steel.

thermal fatigue resistance. Aging of tensile/fatigue specimens for 10,000 h at 700–850ºC continued at ORNL this year. Aging to 1000 h was completed early in 2003, and specimen tensile testing began at Caterpillar later in 2003. Aging to 10,000 h will continue in FY 2004. Microstructural analysis of previous aged or creep-tested specimens of lab-scale heats of CF8C-Plus and CN12-Plus steels was completed in 2003, and tested specimens of the new commercial heats have been identified for microcharacterization early in 2004.

Isothermal fatigue testing and data analysis of the new commercial scale-up heats of CF8C-Plus and CN12 Plus were completed late in FY 2003 at Caterpillar, and thermal fatigue testing is nearly complete. Additional lab-heats of CF8C-Plus were cast at ORNL to define the effects of other minor alloying additions and establish their limits for commercial heats. One of the commercial foundries was chosen by Caterpillar to produce another static sand cast heat and a centrifugally cast heat of CF8C-Plus, and specimens will be made next year.

Conclusions

ORNL and Caterpillar developed CN-12-Plus and CF8C-Plus cast stainless steels that have higher creep strength and better aging resistance than the standard steels. Both cast steels were readily produced and cast as larger size commercial ingots. The commercial CF8C-Plus steel had much more strength than standard CF8C steel at up to 850ºC and is comparable in strength to standard CN-12 steel. CF8C-Plus steel has much better fatigue and thermal fatigue resistance than CN-12 or CN-12-Plus and was therefore chosen as the main focus for exhaust component applications and further commercial scale-up.

Publications/Presentations

P. J. Maziasz and R. W. Swindeman, ORNL, P. F. Browning, Solar Turbines, Inc., and M. E. Frary, M. J. Pollard, C. W. Siebenaler, and T. E. McGreevy, Caterpillar, Inc., *Development of Low-Cost Austenitic Stainless Gas-Turbine and Diesel Engine Components With Enhanced High-Temperature Reliability*, final ORNL report for CRADA ORNL99-0533.

P. J. Maziasz and R. W. Swindeman, "Overview of Selection, Performance, and Development of Austenitic Stainless Steels for High-Temperature Applications," presented as a keynote talk during the plenary session of the ASM Stainless Steel and Specialty Materials Conference, October 7–9, 2002, in Columbus, OH.

M. E. Frary, M. J. Pollard, P. J. Maziasz, and R. W. Swindeman, "Modified Stainless Steel Alloys for High Temperature Engine Components," presented at the ASM Stainless Steel and Specialty Materials Conference, October 7–9, 2002, Columbus, OH.

Special Recognitions and Awards

An R&D 100 Award nomination package was submitted to *R&D Magazine* entitled "CF8C-Plus, Cast Stainless Steel for High-Temperature Performance," by ORNL and Caterpillar last quarter and won a 2003 R&D 100 Award. Several articles on this project have appeared in newspapers, *Energy Insider*, and several technical publications.

Patents Issued

Caterpillar completed an invention disclosure and patent application for cast austenitic stainless alloys with improved performance and filed it with the U.S. Patent Office in December 2000. The title is *Heat and Corrosion Resistant Cast Stainless Steels With Improved High Temperature Strength and Ductility*. Earlier, two separate new patent applications were developed and submitted to the U.S. Patent Office, one on CF8C-Plus steel and the other on the CN12-Plus steel.